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About the Journal

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Custom Work Aids for Distributed Command and Control Teams: A Key to Enabling Highly Effective Teams

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Abstract

This paper presents an approach for designing information technology-based work aids, using a case study approach, to enable high work efficiency and effectiveness (E&E) for a distributed and networked command and control (C2) team. We believe this approach can be utilized to achieve these high-efficiency goals for other C2 teams as well. A common approach to supporting distributed teams is with general purpose collaboration tools (such as chat, whiteboards, file sharing, etc.). Because of the general nature of these tools and because they support only selected aspects of holistic work, the level of work efficiency that can be achieved by these means with teams in the C2 domain is limited. To achieve higher levels of efficiency and effectiveness, we believe holistic, coherent work aiding tailored to the specific work of the team is necessary and can better enable Network Centric Warfare tenets. This paper presents an approach to scoping, analysis, and concept design aimed at achieving those objectives. It also provides an application example of the analysis and design of a demonstration concept developed to support a distributed team of ten different C2 operators geographically distributed between two Air Operations Centers.

Keywords: Collaboration, work-centered design, work aiding, human-computer interaction, human-computer interface, work aiding, teamwork, distributed teams, distributed operations, command and control, user interface design

Network Centric Warfare and Human-Computer Integration

We believe a key enabler of Network Centric Warfare (NCW) is human-computer integration. This is implied and consistent with NCW literature and its seminal definitions, such as: "An information superiority-enabled concept of operations that generates increased combat power by networking sensors, decision makers, and shooters to achieve shared awareness, increased speed of command, higher tempo of operations, greater lethality, increased survivability, and a degree of self-synchronization" (Alberts 1999). To fully realize these goals, key enablers are not only increased access to data and information, but the design of the work aids that enable workers to fully leverage this access while minimizing the potential for "information overload" and maximizing the efficiency and effectiveness (E&E) of the net-centric human-computer "system."

Bandwidth improvements have increased the amount and transport speed of data. While this aids the ability to access critical data and information quickly, it also introduces the risk of sacrificing those benefits by the very volume and form of the data and information itself. Human beings have a finite capacity to process information, and are increasingly becoming overwhelmed by the volume of data and information available through the Internet and other applications and mediums. By its very nature, C2 work is complex, notwithstanding the additional burden of sorting through superfluous data and having to learn the idiosyncrasies of information technology-based work aids and software applications. We believe the amount of overhead introduced by poorly designed human-computer interfaces to these applications can be significantly reduced and have a direct positive impact on operational effectiveness. For

the purposes of this paper, "overhead" means unnecessary cognitive and procedural burden associated with using work aids.

The Air Force Research Laboratory's Human Effectiveness Directorate has been developing an approach called Work-Centered Design (WCD) (Eggleston 2003) to design information technology-based work aids with a goal of maximizing the E&E of performing work. It is based upon a holistic model of work and design principles with a goal of reducing overhead by tailoring work aids to the worker and their uniquely situated work support requirements whether working individually or as part of a team.

Holistic Work Practice

In previous research, Eggleston (2003) posited that there are four context-independent classes or facets of work activities that can be useful in modeling work practice. They are: decision making, product production, collaboration and coordination, and work management. Based on our observations of naturalistic (Klein 1998) C2 work practice, workers typically multiplex between these four activity types continuously and move between them in unpredictable ways. The proportion of the total time a worker spends on any of the four facets varies depending upon specific work assignments, duties, and emergent work requirements. Rarely, if ever, is it true that an individual worker does not engage in aspects of all four facets at some time.

For example, a C2 worker's assigned and assumed tasks are rarely, if ever, exclusively to "collaborate." From this holistic work practice perspective, one of the problems with general purpose collaborative tools (such as chat, whiteboards, file sharing, etc.) is that they support only a single facet of multifaceted C2 work. In addition, many require a high degree of synchronous interaction among collaborating workers, and provide limited support for asynchronous and other activities that enable the self-synchronization goal of NCW.

Cognitive and Procedural Overhead

As mentioned earlier, we believe another key strategy to enabling high work E&E is minimizing the overhead associated with workers doing work. Much of this overhead is introduced by information technology-based work aids or tools that are not well matched with worker requirements across the span of routine and emergent work that the worker must perform. The more frequently the worker must task switch from thinking about "direct" work issues to thinking about how to use work aids, the greater the cognitive burden, which decreases work speed and increases the possibility of committing errors. The more procedures the worker must engage in to find, fuse, and format data or information and arrange it into an "actionable" form, the less productive the worker will be. Of course, procedural burden also induces some degree of cognitive burden associated with activities such as remembering how to, for example, find specific data or input data to enable computation of desired information necessary to enable other work activities.

Tailored Work Aids

General purpose collaborative tools (such as chat, whiteboards, file sharing, etc.) are designed to be context independent. For this reason, they usually incur significant overhead for the workers using them. It has been our observation that in many cases the nature and subject matter of the work performed by C2 workers and teams has recurrent elements. Although many specific details and emergent work requirements cannot be anticipated from work session to work session due to unique situation dependencies, at some level there is a persistent structure and nature of the work phenomena and worker activities (Eggleston et al. 2000). This offers the opportunity to develop tailored work aids anchored on this persistent structure as a strategy for reducing overhead and increasing worker E&E. This tailoring involves understanding and designing to support the worker's unique first-person perspective on the work (Eggleston et al. 2000), including requirements to act independently and at times

as part of a team, by designing the aiding to provide just the right information, in the right form, including context as necessary.

General purpose collaborative tools are useful and provide valuable work aiding, especially when the nature of the interactions cannot be anticipated. Because of their context-independent nature, general purpose collaborative tools are not intended to be aligned with the specifics of any particular work domain and thus do not have a tailored fit with workers' mental models of the domain, work phenomena, and work activities. While workers may be able to adapt to some mismatches between the user interface and the work requirements, excessive overhead is typically incurred in order to use a mismatched aid. Aligning the work aiding design with workers' mental models of work and domain helps to minimize this overhead and helps provide intuitiveness for the work aids, because it provides specific information and context in forms that match how workers understand the work domain and phenomena, and perform work activities.

In summary, we believe the key to maximizing individual and team E&E for C2 workers is designing work aids that support holistic work practice across a selected scope of work activities, including collaborative aspects, and are tailored to the unique first-person perspectives on the work the workers perform.

Case Study: U.S. Air Force Coronet Mission

In this case study, we applied the Work-Centered Design approach to support a geographically distributed C2 team. The analytic and design emphasis was scoped to understand and design work aiding to support interaction and synchronization activities among workers. To support this, it was also necessary to support certain aspects of unique individual work necessary to support efficient and effective interactions.

Case Study: Background

In order to understand and support specific work aiding design requirements for the selected user set and work objectives, an initial team-level work support goal was identified: To design and demonstrate a work-aiding concept to support geographically distributed work groups planning and executing U.S. Air Force Coronet missions. ("Coronet" missions transport aircraft and possibly personnel from one location to another on relatively long flights, which typically include a transoceanic leg.) The design concept was to create a work-aiding environment to support this diverse team in their singular goal to successfully plan, launch, and execute the missions with an emphasis on supporting interaction and synchronization between workers. In examining work practice, we found that to achieve this objective, workers must understand and adapt to changes in plans and/or unexpected events during planning and execution (such as due to changes in weather or aircraft maintenance issues). The design goals were:

- To design a work aid tailored to this specific mission type, yet tailorable by individual users to support their unique first-person perspective, while at the same time prohibiting a level of tailor-ability that would compromise necessary awareness of the operational environment, the responsibilities of workers or mission objectives.
- To design a work aid in which essential elements are immediately recognizable by all user groups, thus enabling workers to rapidly understand and act in a manner synchronized with the other team members.
- To design a work aid to support both direct and indirect interactions with others to achieve individual and overall team goals.

Case Study: Analysis

The organizations that supported this mission included two operations centers (one under the Air Combat Command and one under

the Air Mobility Command) in different geographic locations, each with five separate and distinct worker types performing essential mission-related activities. Each of these ten worker types include individuals with highly specialized skills providing varying levels of support depending on the mission phase. The analysis, or knowledge acquisition, was conducted with each of these ten worker types. Because we used a work-centered analytic approach, we attempted to understand actual work practice initially independent of current information technology and independent of artificial processes that the information technology may have created. The process of deriving such information often involved understanding the current processes and technologies and working backward, in collaboration with users, to understand the actual work practice. In the process, we learned that each group had its own software tools, with little shared data or information across groups. The sharing that did occur was supported by shared data access but required periodic user access to check for changes and incurred significant overhead work to integrate it with other information and transform it into an actionable form.

The analysis process involved gaining a detailed understanding of the users and their work from both a structural and process perspective for each of the ten worker types using both direct and indirect techniques. Initially, individual and group interviews were conducted at the work locations and were followed by remote group and individual telephone conferences. The interviews were structured with deliberate questioning to try to understand the work structure. Redirection of conversations occurred frequently to ensure that the needed information was being secured with as little superfluous information as possible. This was necessary in order to control the volume of the data received as well as to ensure that the key information was gathered.

The analysis was conducted with representatives of each worker type. In all cases, two or more representatives of each worker type participated. The information was analyzed and organized separately for each worker type and then distributed to the individual

participants for review. This iterative review process of the knowledge acquisition results occurred for all worker types, and subsequently for leadership participants and at all levels of the organization. This was found to be an important step in ensuring accuracy of the information collected as well as providing a means of exploring inconsistencies between team and individual work.

The terminology used by the ten worker types was carefully studied, as was the language they used to communicate with each other. Other analyses included cognitive loading, order of tasks, volume and frequencies of work elements, individual case loads, and "worst case" scenarios and physical work environment issues.

Results of the analysis indicated that there are specific points of collaboration that occur at varying times for different worker subsets. Results also indicated an overall shared knowledge base of information for all worker types as well as distinct sub-group level and individual worker type-specific knowledge and information. These shared knowledge bases contain information that is critical for communication between the worker types. Other key findings included the detailed information that needs to be communicated during specific timeframes between specific worker types. However, separating out this shared knowledge base necessary for collaboration involved understanding both the detailed needs of each worker type as well as a higher, overall mission-level perspective. It was often the case that the shared knowledge and collaborative needs of the team as a whole, or of sub-groups, were only evident after gaining a detailed understanding of the process, structure, information needs, decision points, and challenges faced by the individual worker types.

Analysis indicated one of the most important aspects of supporting this mission type was enabling the workers to track the progress of planning, launch, execution, and recovery over time. In addition, immediately understanding significant changes and adaptively re-planning as necessary was a key element of the ongoing work and it involved the same core set of shared information across all timeframes, with additional information specific to each timeframe. A

key was enabling each worker type to see the work phenomena, domain, and domain objects as a coherent whole from a cognitive perspective. Even the workers who spent the largest percentage of their time supporting these missions were not involved in every aspect of the mission. A picture of the mission helped workers to cognitively integrate the high-level goals of the mission with the individual worker goals and synchronize and orient work with respect to the larger team-level objectives. This was true whether an individual worker's role was extensive or limited.

Case Study: Iterative Design Process

The analysis phase resulted in large amounts of data for each worker type. Providing all of this information to users without regard for timeframe or specific worker requirements would have resulted in a work aid design that could have created or perhaps replicated a cognitive overload situation. Traditional methods of ameliorating this and determining project scope often focus on a single timeframe or single worker type or group type and provide all of the information necessary within a selected scope. That is one method of solving the information overload problem, but it has limitations because it provides a "tunnel-vision" view for workers or sets of workers without regard for the many interdependencies and communication requirements to support the overall mission. Taking a higher level holistic, gestalt perspective is one approach to remedying this. On the other hand, focusing on this perspective does not necessarily provide information and tools for every work task that every worker type needs in order to accomplish all of their work. By designing a single extensible framework based on a holistic understanding of both individual and team requirements, we demonstrated a complete, coherent work-aiding environment for all targeted workers regardless their specific roles. Existing and additional information technology-based tools can be readily integrated in a manner consistent with the mental models of both individuals and larger, shared mental models of the team.

Once the scoping decision was made, the information gathered during the analysis phase was translated into the first draft of a work-aiding design. That was the beginning of an iterative design process that utilized paper and pencil mock-ups, informal slide mock-ups, and finally an interactive, software-based prototype of the design, which itself had two iterations.

Numerous design reviews were conducted with users via individual telephone conversations as well as group telephone conferences. The conferences included individuals of the ten different worker types in various configurations based on what was being reviewed. MS PowerPoint versions of aiding concepts were reviewed with intended users, and discussions of how the work structure matched or did not match these concepts ensued. Similar to the knowledge acquisition sessions, these reviews were highly structured, with the focus being on the work itself, not on specific work aid design elements. This is an important distinction. Workers/intended users are typically able to identify whether a design meets their needs, and may be helpful in suggesting work-aiding design changes. However, the issue of design was not the important content of the discussions. Clarifying and refining the designer's knowledge of the work is what typically occurred during these meetings. Design changes then flowed very easily from such knowledge. An example of this is an instance in which an intended user suggested that a work aid element (an airfield) blink when its status changed. This comment led to a discussion and refined understanding of what was important, when it was important, and eventually led the designer to include another set of options. A blinking element in a work aid display is useful in very limited circumstances and was not appropriate here. However, the worker is the expert on their work and, in this case, was identifying important holes that existed in our knowledge of the work at that point by making such a comment.

Case Study: Tailored Work Aiding Concept

The knowledge acquisition results were translated into a work aid design that mirrored the work domain, objects, and structure itself as perceived by the workers' first-person perspectives. This meant enabling each user to understand the details, context, timeframes, decision points, organizational relationships, and all other details involved in creating a deceptively simple work aid. Although deceptively simple, many details were analyzed in order to create a design that contained only the necessary information in the appropriate form and at the appropriate times. That is, our goal was to design the work aiding to fit and support the workers' naturalistic work practice without getting in the way. We designed with the intent that all user types should be able to view the work aid and rapidly recognize all or most elements. This is possible because the work aid is an actual representation of the work domain, objects, and structure. In this case, the structure of the work aid itself reflects the structure of the work and the terms used are based on the users' ontology.

This design is significantly different than the current information technology-based support the users were using. Workers needed to share information at various timeframes while obtaining and maintaining relevant common situation awareness (SA). The overhead, however, of achieving common SA was great because different workers used different tool sets designed typically to optimize the work for each worker type and therefore often had inconsistent and differing levels of SA. For one worker, simply arriving at a relatively common SA might involve gathering information from three or four different sources, often in different media. Another worker might, for example, make a phone call, download information, view a hardcopy map, and run two different application programs before having a complete and current view of the current state of a mission. Another worker may make a phone call, download information from a different source, and run additional unique tools in order to achieve a similar level of SA. Workers must do this in addition to generating their own work products. Much of this is technology-induced overhead and we believe this could be reduced by the

creation of work aids that provide the appropriate domain and work object representations. These workers possessed specific expertise and still needed to perform specialized functions that relied on specific information and an understanding of the work state, objects, and context. That specific information only became part of the overall view of the mission, however, when there were specific shared knowledge and collaboration needs. Then, as soon as appropriate, the information automatically flowed into the work aid with the appropriate level of context. Examples of this include many planning documents including the mission plan and multiple versions of flight plans, which, as a normal part of the Coronet planning process, are updated at specified timeframes.

An example of this in the Coronet mission domain occurs when an authorized worker must make a mission launch, or "go/no go," decision, which requires collaboration and agreement between authorized workers (only designated workers from each location have the authority to make "go/no go" decisions). Some of the information that individuals require before making this decision includes the current status of relevant airfields, aircraft, diplomatic clearances, aircrew availability, and altitude reservations. Rather than requiring workers to check multiple aids or sources for this information, it is provided in a single panel of the work aid shown in Figure 1. In this design, color is used as a secondary cue to indicate status and the user can click on any of the four tabs to view the respective statuses. This information is available and continually updated from initial planning through launch and recovery, and all workers have access to the same information. The worker responsible for the"go/no go" decision might reference this status information several times during the course of planning and can request automatic notification based on user-selected exception parameters if, for example, a specific exception threshold is met, and an instance in this particular design a status indicator turns red. Other workers, depending upon their roles, may choose to view this information frequently, infrequently, or perhaps not at all.

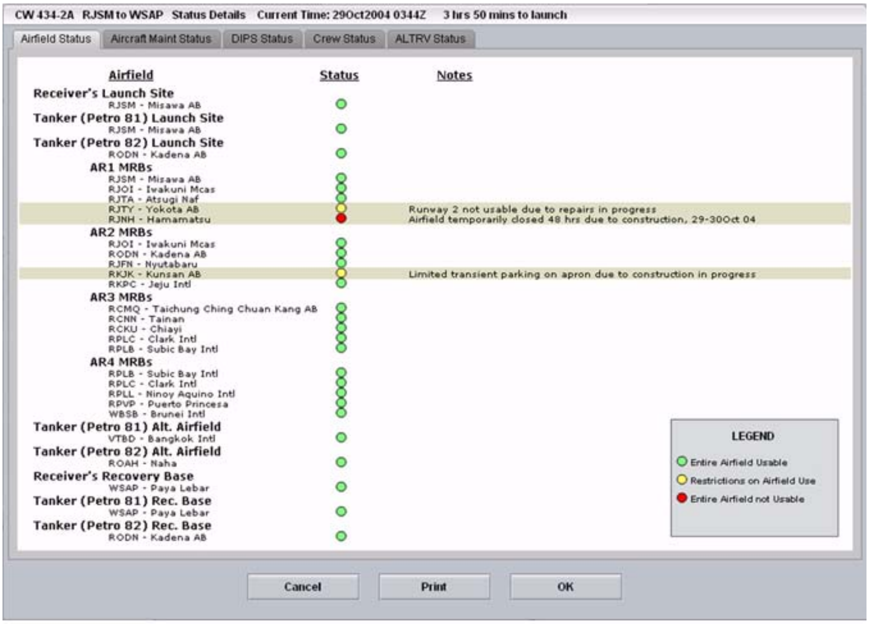

Figure 1. Status panel with tabs for quick access to important mission status information.

Other workers are more critical for certain aspects of the mission but less involved in daily decisions. For instance, the worker type responsible for supplying aircraft and aircrew resources needs to know equipment information, launch and recovery dates, and any changes to these, and needs to know this information as soon as it is available. From their unique first-person perspective and responsibilities, these workers do not need to track detailed mission progress but do need to know when there are changes that affect aircraft and/or aircrew availability, or when there are new requirements for aircraft and/or aircrews. While they seldom need more mission-specific information, their role is just as critical as other workers who do because without aircraft and aircrew assets the missions cannot be executed. In addition, the work aid design relieves these workers from actively obtaining and maintaining relevant situation awareness (i.e., accessing and monitoring information sources to determine if something significant has changed) by providing immediate notification when relevant

changes do occur. Workers want to be told only what they need to know when they need to know it and no more, thus minimizing overhead. This objective was instantiated by providing an automated pop-up message window and/or e-mail notification if the user-selected exception conditions occur. If an exception condition occurs, these workers can then choose to access the complete work aid and view a particular mission and/or mission details (by clicking a link in the e-mail or direct access within the application). In many cases, workers will have sufficient understanding to support confident action without even accessing the complete work aid. This reduces the cognitive and procedural load of constantly checking for changes or new requests in case a new change or exception condition has occurred. It is more efficient and can occur seamlessly through technology. Figure 2 is the aid that allows workers to set user preferences and exception notices.

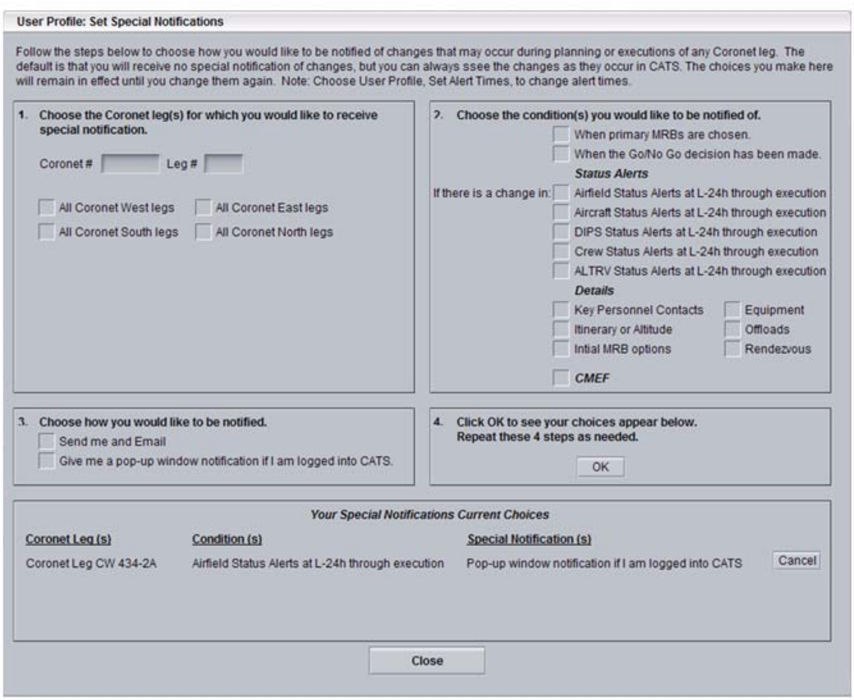

Figure 2. Preferences panel that allows users to customize how they would like to receive information on status alerts.

Because this design was being developed to support a distributed C2 team, prior to detailed analysis we suspected that aiding similar to chat tools would be a logical collaboration element in the work aid design. However, after our analysis we believe this to be true very infrequently and only within very circumscribed and specific work contexts. For instance, in the work aid concept there are three areas in which all workers can contribute information to decision makers in a chat-like, text-entry manner. These areas are related to specific decisions or mission phases and are utilized within specific contexts and timeframes. Figure 3 is a panel that workers can use to communicate and log information relevant to the "go/no go" decision.

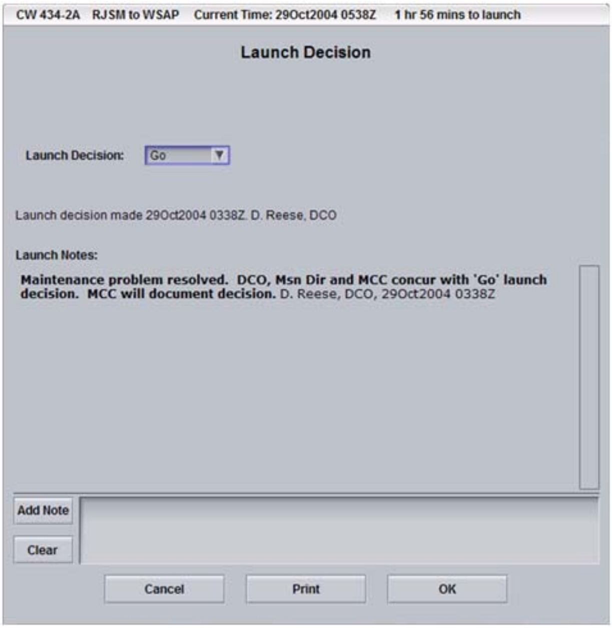

Figure 3. Launch decision panel that allows users to input and view launch decision and relevant information.

One of the key collaborative decision makers often did not have access to a computer terminal during the launch decision timeframe and made phone calls to communicate information. Our design concept allows the collaborating decision makers to log and make collaborative results available to other team members as soon as the

decision occurs, including cues in other panels indicating "go" or "no go" status and the date and time that determination was made. This enables other workers to continue to focus on their individual responsibilities while being cued on this type of relevant change when it occurs, and with rapid access to more specific information such as in the panel on Figure 3.

While we could not show the main/home geo-referenced display due to the sensitive nature of the information, we hope the examples presented illustrate some of the specific ways the work aid design concept was tailored to support interaction and synchronization from both individual- and team-level perspectives.

Case Study: Results

After iterative analysis, design, and refinement, a final concept description and demonstration were presented to intended users and their unit commanders. Feedback was very positive. This work-aiding concept is now in the U.S. Air Force acquisition system and is scheduled to be integrated into an information technology "System of Record," which will make it available to the Air Force C2 operators supporting Coronet mission planning and execution. Users and leadership listed the following key benefits from this new approach and this particular work-aiding concept:

- Increased "safety of flight" by enabling increased situation awareness, proactive problem identification, rapid understanding, analysis, and decision making.
- A new plan-monitoring and "flight-following" capability that increases relevant individual and shared situation awareness, automated monitoring, and proactive identification of potential problems, adding to increased safety of flight.
- Timely shared situation awareness is available for all worker types, decreasing the likelihood of errors and allowing an increase in the ability to self-synchronize without explicit collaboration.

- All major relevant mission and constraint information is provided in a single integrated understand-act work aid. This provides better understanding of the current situation, potential problems, and optimal alternatives. It also facilitates more flexible, rapid, and timely re-planning if necessary, which is especially important in time-critical and hazardous situations.
- Facilitates distributed operations. At the time of the presentation, the two organizations were using different systems and views of the same source information, which in some cases led to similar yet unwittingly different understandings of relevant information, thus increasing the chances of miscommunication and errors.
- Information is provided within its relevant context to afford rapid understanding and effective action. The allows increased work efficiency at the individual, unit, and organizational levels by minimizing the overhead work of finding, fusing, and formatting information into an actionable form. Time can be saved by eliminating much of the overhead work of producing products that become the object of collaborative and/or information sharing activities. These activities can be supported directly by the facilities and information forms in the work aids themselves.
- More efficient collaboration and coordination is facilitated. This enables more effective and rapid information flow and understanding by allowing multiple avenues for collaboration and coordination: explicit, implicit, synchronous, and asynchronous.

Summary and Conclusions

This paper illustrates the use of work-centered analysis and design to create a holistic work-aiding concept that increases the efficiency and effectiveness of a distributed, networked C2 team. Early feedback from targeted end-users and their leadership identified significant increases in efficiency and effectiveness and operational benefits that will result from the use of the work aid in conducting planning, execution, and rapid adaptive re-planning in a demanding and dynamic operational environment. We believe this

approach can be utilized to achieve the same E&E goals for other C2 teams as well and perhaps provide a foundation for the development of work aids that leverage and enable Network Centric Warfare tenets.

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